PROSPECTING WITH A COUNTER

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By

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INTRODUCTION

Many features of uranium deposits are not understood, but one thing is certain: uranium ores are radioactive. For this reason portable counters which detect and measure radioactivity have proved useful in the search for uranium and other radioactive elements. A new gadget—the field counter—has thus become standard prospecting equipment.

This booklet has been written to summarize information on field counters—their operation, use, abuse, and their application to prospecting, mining, and geologic problems. Practical problems have been emphasized and theory has been minimized, but it has been necessary to introduce a certain amount of theory in order to provide background material.

The limitations of counters have been given special attention, because failure by miners and prospectors to recognize these limitations has sometimes resulted in costly errors. It should be recognized, however, that this booklet cannot explain all the effects measured by all counters under all circumstances. Most effects can be interpreted through the principles discussed herein,

but in prospecting, one soon learns that nature does not always seem to follow the rules.

In preparing this discussion, the author has relied on his own experience, the experience of fellow geologists of the United States Atomic Energy Commission and on published information.

The author wishes to express his appreciation to John Robb, United States Geological Survey, Denver, Colo., who kindly prepared the sketches.

Chapter I

TYPES OF COUNTERS

Buying a counter is somewhat like buying an automobile—one has a choice of models which range widely in style, size, and price. Some instruments cost more than $1,000, whereas others can be bought for less than $50.

Regardless of their apparent variety, however, all counters belong to only three fundamental types. The most commonly used type is the Geiger counter. A second type, the scintillation counter, has recently appeared on the market. Because of its high sensitivity, this counter is proving popular in spite of its somewhat higher cost. A third type, the ionization chamber, has been used in prospecting, but has not proved popular and hence is not discussed here.

GEIGER COUNTERS

The Geiger-Müller counter was developed in 1928 as a sensitive device for measurements of radioactivity in

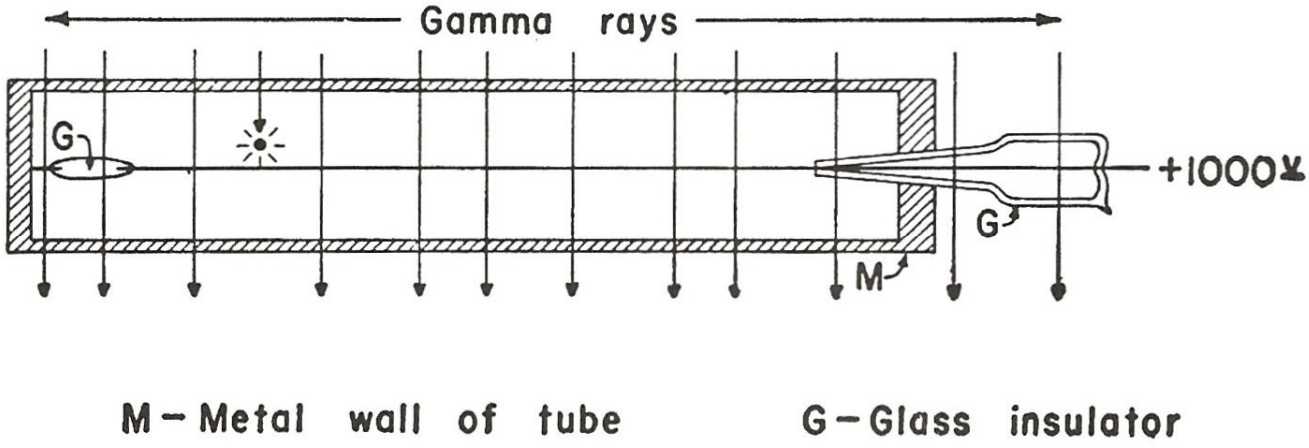

FIG. 1.—Cross section of a Geiger tube. In operation, the center wire is charged to about 1,000 volts. Of the many gamma rays which strike the tube, only a few (one is shown) strike a gas molecule within the tube in such a way as to discharge the tube.

the laboratory. The first field instruments were clumsy, but the modern prospecting counter is a compact, rugged instrument. Specialized counters have been designed for a variety of specific jobs, such as prospecting from the air and examining bore-holes.

The heart of the Geiger counter is the Geiger tube itself (fig. 1). This is of glass or metal and may be from a few inches to several feet in length. In some counters, the Geiger tube is contained within the counter case, whereas in others the tube is separate, and connected to the case by a conducting cable. The tube is filled with one or more gases, such as helium, argon, or krypton, and in operation a positive charge of about

1,000 volts is applied between the center wire and the metal wall of the tube.

A radioactive element such as uranium emits either alpha or beta particles and may emit gamma rays as well. When a Geiger counter is placed near such an element the tube is struck by the radioactive emissions. Alpha particles are stopped by the tube wall. Beta particles have greater penetrating power and some of these can enter the tube and be recorded. Gamma rays, which are still more penetrating, can penetrate the wall, but most pass completely through the tube with no effect. A few gamma rays—about 0.5 percent—enter the tube and interact with a molecule of the enclosed gas to produce electrons. These negative electrons are attracted toward the positively charged center wire and produce a negative electrical pulse as they collect on the wire.

In addition to the tube, a Geiger counter contains a battery-operated power supply, an amplifier, and one or more indicators (fig. 2). The indicator may be a neon light, or a meter, which gives a visible indication of radioactivity, or a headset, which gives an audible indication. The light flickers and the earphone clicks each time the Geiger tube discharges. On the other hand, a meter gives an average measurement of radioactivity. Most counters have jacks into which a head-

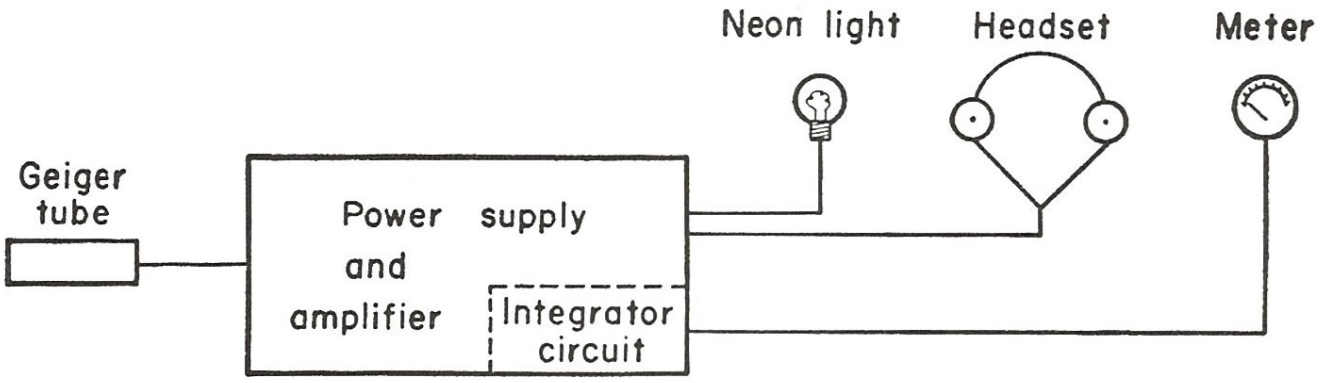

FIG. 2.—Block diagram of a Geiger counter. In some models the Geiger tube is contained within the counter case.

set can be plugged. Neon lights are found on less expensive counters and meters on more costly models.

SCINTILLATION COUNTERS

Although most counters used in prospecting are Geiger counters, a second type of instrument—the scintillation counter—has recently been put on the market. Present models cost more than Geiger counters, but they offer several advantages, such as higher sensitivity to gamma rays.

It was noted above that a Geiger detects gamma and beta rays by the ionizing effect they have upon gases contained within the Geiger tube. A scintillation counter, like the Geiger counter, also measures gamma and beta rays, but it depends upon another property: the ability of gamma (and beta) rays to produce tiny mo-

mentary flecks of light (scintillations) in crystals of certain compounds such as sodium iodide and potassium iodide.

The chief advantage of a scintillation counter is that it responds to a large proportion of the gamma rays that penetrate the crystal. Depending on the type and size of the crystal, scintillations are produced by 50 percent or more of the gamma rays that strike the crystal. In contrast, most Geiger tubes are discharged by less than 1 percent of the gamma rays which penetrate them. This means that the crystal counter is more sensitive.

The arrangement of component parts is similar in both types of counters. In place of the Geiger tube, a scintillation counter employs a small crystal, usually made of sodium iodide, attached to the end of a light-sensitive photomultiplier tube. Both crystal and photomultiplier tube are sealed in a light-tight unit so that the instrument cannot be triggered by sunlight. The tube "sees" the scintillations produced in the crystal and transmits them as electrical pulses. These are amplified and passed through an averaging circuit to a recording meter.

A few general suggestions about the use of a Geiger counter are noted below. (Additional information about counter maintenance is contained in chapter VI.)

1. Because of the high voltage necessary to charge the Geiger tube, it is important that the equipment be kept dry, otherwise the counter may short out. Some instruments are especially sealed by the manufacturer against moisture, but unless this has been done the counter should not be used in a humid environment, such as a wet mine.
2. The counter should be protected from contamination by radioactive clothing, mine or mill dust or ore specimens.
3. If individual clicks cannot be distinguished in the earphones or the needle swings to the top of the indicating dial, the radioactive field is so intense that the counter may be damaged. Use a less sensitive counter setting or move away from the source of radioactivity.
4. The counter should be turned off when not in use in order to conserve the batteries.
5. To obtain an accurate reading, keep the counter away from any watch, compass, or other instrument which has a luminous dial. The luminous paint contains a radioactive radium compound.

A Geiger counter is adequate for most geologic and mining problems. However, the much higher sensitivity of a scintillation counter makes it especially useful

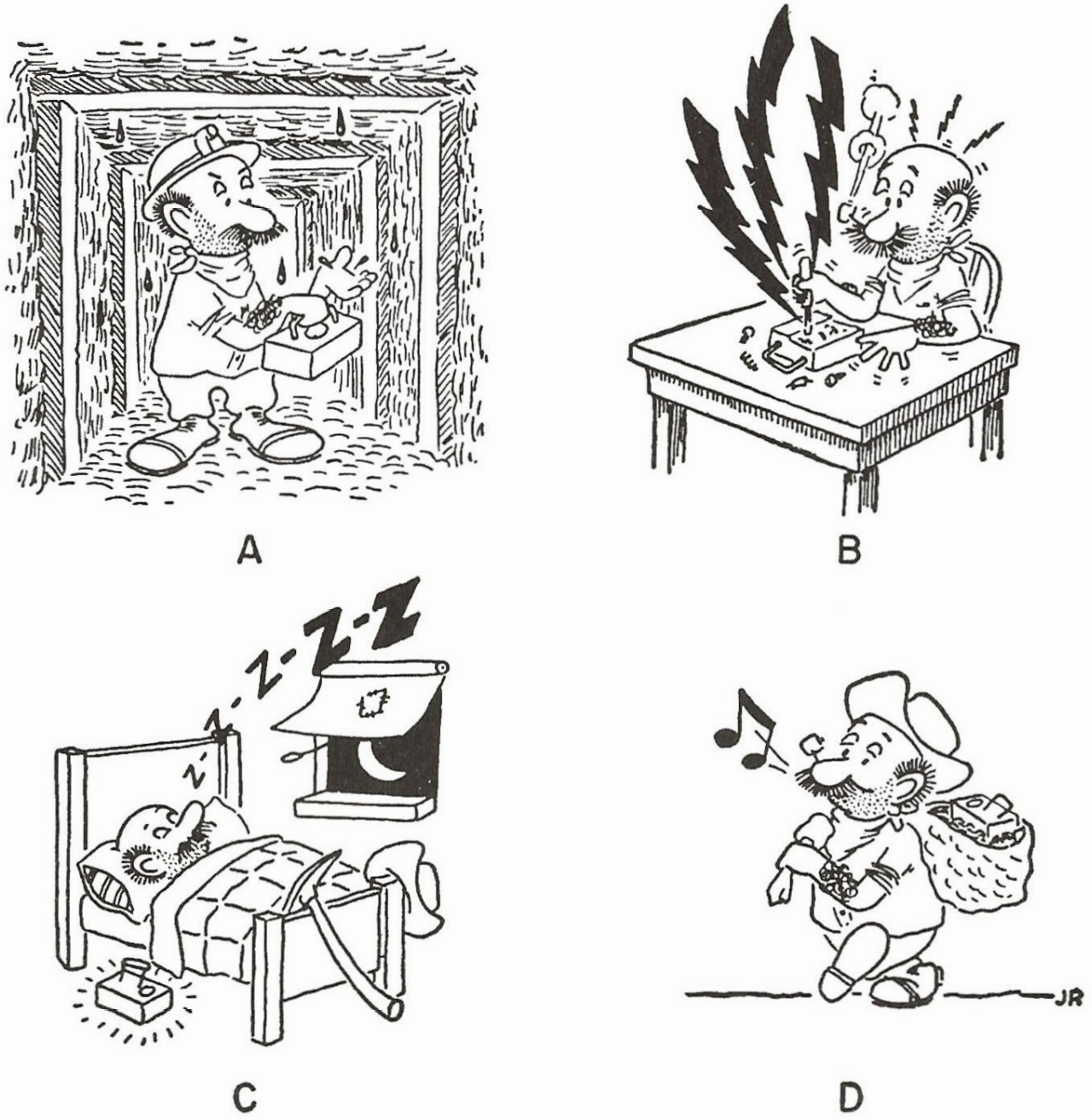

FIG. 3.—How not to use a Geiger counter. (A) Unless specially protected against moisture a counter will not work well in a wet mine. (B) Do not change batteries without following the manufacturer's instructions. (C) Do not leave the counter on when it is not needed. (D) Do not carry the counter with ore specimens.

for measuring low levels of radioactivity, for making radioactivity surveys, and for prospecting from the air.

Many kinds of counters are manufactured for field use and before purchasing one, the user should determine which type most nearly fits his needs and pocketbook. A number of counter manufacturers are listed in appendix A.

Chapter II

GAMMA RAYS

Since the discovery of radioactivity in 1896, researchers have attempted to determine the nature of the emissions produced. In the course of this work many types of radiations have been discovered: alpha particles, beta particles, gamma rays, protons, positrons, neutrons, mesons, neutrinos. Of these, only gamma rays are of importance in the present discussion because field counters are mainly gamma ray detectors, as was noted in chapter I. Some Gieger counters have a metal sleeve which can be moved to expose the Geiger tube directly to radiation, and in this way some beta particles can be detected.

Gamma rays are like X-rays. They—

1. Are not affected by electric or magnetic fields.
2. Travel in straight lines at the speed of light.
3. Produce scintillations in certain crystals.
4. Have neither mass nor charge.
5. Blacken photographic film.

6. Penetrate matter.
7. Ionize gases.

Like X-rays, gamma rays can penetrate matter, but the gamma rays produced by uranium minerals have only slight penetration due to their relatively low-energy level. The ease with which gamma rays are absorbed by any material depends on its density. The gamma rays from uranium are stopped by approximately—

3 inches of lead.
1 foot of rock.
2½ feet of water.
Several hundred feet of air.

Since the outer foot of a rock mass absorbs almost all gamma radiation beneath it, a counter cannot detect gamma rays which come from a source deeper than 1 foot. Once the rays escape from the rock, however, they can travel for some distance through air. In other words, a counter measures only the gamma rays from the *outer foot of a rock mass*, and it cannot detect radioactive ores deep within the rock.

This is a very important limitation on the usefulness of a counter.

Chapter III

RADIATIONS OF URANIUM

To understand the uses and limitations of counters, it is necessary to know a few facts about uranium and its many radioactive daughter products.

Any element can be artificially made radioactive by bombardment with suitable particles in an instrument such as a cyclotron. Several elements, however, are unstable in their natural state and these undergo spontaneous radioactive decay. One such element is uranium. Uranium ore contains two kinds of uranium atoms—one with atomic weight of 238 and the other with atomic weight of 235. Uranium-238 is much more abundant than uranium-235, by a ratio of 140 to 1. Because of its greater abundance, uranium-238 is largely responsible for the radioactivity of uranium ore.

When uranium-238 disintegrates, it forms thorium-234. This, too, is radioactive and decays to form protactinium-234, also a radioactive element. Other radioactive elements are formed by this progressive

disintegration until finally an inactive element, lead, is formed. Thus, uranium-238 is the parent element of a long series of radioactive elements. Each is formed by radioactive decay and each yields another radioactive element. The series begins with uranium-238 and includes 13 radioactive daughter elements, 1 of which—radon—is a gas. The series ends with lead, which is inactive and undergoes no further decay.

The meters on most counters are calibrated in either counts per second or milliroentgens (abbreviation—mR) per hour. A milliroentgen is 1/1000 roentgen (abbreviation—R).* The roentgen is the standard unit for measuring X-rays and because of the similarity between these and gamma rays the unit has been used in counter calibration.

Table 1 shows the elements in the uranium series. All are present in most uranium ores. The first column lists the name of each element and its atomic weight. The second column, "Radiometric designation," notes the term which is commonly used to identify each mem-

*The roentgen (R) is defined as that quantity of X-radiation which will produce one electrostatic unit of ions in one cubic centimeter of air under standard conditions of temperature and pressure. The roentgen is a measure of the quantity or amount of radiation, regardless of whether that quantity is produced quickly by intense radiation or slowly by moderate radiation. Therefore, the rate of gamma ray production—or, in other words, the intensity of radiation—must be expressed as roentgens per unit of time.

ber of the series. These designations were applied by early researchers before it was recognized that the radioactive members of the series are identical with the various elements. The "Half life," column 3, is the time required for each radioactive member to lose half of its radioactivity; hence the half life figure is a measure of the speed of decay. This varies quite widely: UI has a half life of 4,510,000,000 years; RaC′ has a half life of 0.0002 second. In 1 half life an element loses 50 percent of its original radioactivity. In 5 half lives it loses 96 percent of its original radioactivity, and hence is essentially exhausted. Column 4, "Radiations," notes the type of emissions from each element. The average strength of each type of emission is noted in millions of electron volts (mev.).

Column 4, "Radiations," is particularly important in understanding counter readings. Each element emits either an alpha or a beta particle, and in addition, five of the elements are gamma emitters. It is important to note that uranium itself does not give off gamma rays. Therefore the Geiger counter, which is primarily sensitive to gamma rays, *cannot detect uranium directly.* Instead, the counter measures the radiations of the five gamma ray producers, particularly the strong emitters RaC and UX_2. Only when the gamma ray emitters are present in amounts proportional to the amount of

uranium can the counter give an accurate measure of the uranium present.

TABLE 1—THE URANIUM SERIES

Element	*Radiometric designation*	*Half life*	*Radiations (mev.)*		
			Alpha	*Beta*	*Gamma*
Uranium-238	UI	4,510,000,000 years	4.21		
Thorium-234	UX_1	24.1 days		0.18	0.09
Proctactinium-234	UX_2	1.1 minute		2.32	.80
Uranium-234	UII	269,000 years	4.75		
Thorium-230	Ionium (Io)	82,200 years	4.66		
Radium-226	Radium (Ra)	1,600 years	4.79		.19
Radon-222	Radon (Rd)	3.8 days	5.49		
Polonium-218	Radium A (RaA)	3.1 minutes	5.99		
Lead-214	Radium B (RaB)	26.8 minutes		.65	
Bismuth-214	Radium C (RaC)	19.7 minutes		3.15	1.8
Polonium-214	Radium C′ (RaC′)	0.0002 second	7.68		
Lead-210	Radium D (RaD)	22.2 years		.025	.047
Bismuth-210	Radium E (RaE)	5.0 days		1.17	
Polonium-210	Radium F (RaF)	139 days	5.30		
Lead-206	Radium G (RaG)	Stable			

This is a fact of prime importance, since it is a limitation on the accuracy of any uranium analysis made by measuring radioactivity.

Under what conditions, then, are the gamma ray emitters present in normal amounts? They are present in normal amounts if the material tested is in radioactive equilibrium.

What is meant by radioactive equilibrium? If uranium is freshly purified and separated from its radio-

active daughter elements, it immediately starts to decay and re-form its daughter elements. As these progressively decay all the elements normally in the decay series gradually accumulate. Finally, after about 1 million years, each element is present in such amount that it decays at the same rate as it is produced, and thereafter no further change takes place in the quantity of any daughter element. The series is then in radioactive equilibrium.

When uranium ore is in equilibrium, a certain fixed proportion of each daughter element is present, whether the ore contains 0.1 percent uranium or 50 percent uranium. Therefore, at equilibrium each gamma emitter is present in its normal amount and the radioactivity measured by a counter is dependent on the amount of uranium present; hence, a counter reading can provide a reliable indication of the uranium contained in the ore.

When is a uranium sample in equilibrium?

RADIOACTIVE EQUILIBRIUM

Of primary importance is the fact that about 1 million years are required for newly purified uranium to reach equilibrium with its daughter products. All the uranium now contained in rocks was, of course, present when the earth was formed. Since the earth is esti-

mated to be about 3,000 million years old, all uranium in the earth is also of this same age. It might then be expected that uranium everywhere should be in equilibrium. This would indeed be the case if it were not for the fact that some uranium-bearing materials have undergone chemical or physical change which has separated the uranium from its daughter elements. If this change took place within the past 1 million years, insufficient time has elapsed for the separated uranium to re-form its daughter elements and establish equilibrium again.

Lack of equilibrium, then, results from the separation of uranium from its daughter elements within the last 1 million years. In nature this can result from (1) attack of uranium minerals by solutions such as ground water and (2) the loss of the gaseous daughter element radon. The first of these is important in many geologic problems, but the second is important only under special conditions.

Inequilibrium due to attack by solutions is a common result of the oxidation and weathering of outcropping uranium deposits, especially deposits which contain pitchblende and sulphide minerals (such as pyrite, chalcocite, and chalcopyrite). Ores of this type are found in the Shinarump conglomerate of southeast Utah and in vein deposits such as those at Marysvale, Utah.

Oxidation of pitchblende-sulphide ore forms acidic ground water due to the formation of sulphuric acid by the oxidation of the sulphide minerals. Uranium is soluble in acid waters and tends to be removed in solution, but radium is much less soluble and its compounds tend to remain behind in the leached outcrop. Therefore, the outcrop may be radioactive due to the presence of the gamma-emitting elements RaC and RaD, even though much of the uranium has been lost in solution. As a result, a sample taken from the outcrop may give a high counter reading, but a chemical analysis proves that the uranium content is low.

In places secondary uranium minerals—such as autunite, torbernite, and schroeckingerite—are deposited by ground water. Most such deposits are out of equilibrium. The equilibrium conditions usually vary widely from sample to sample and therefore counter readings are apt to be quite unreliable. Lack of equilibrium in these secondary minerals results from the fact that the minerals were deposited less than 1 million years ago. Hence, gamma-emitting daughter elements have not yet accumulated in their equilibrium amounts, and more uranium may be present than is suggested by the counter readings.

Movement of radon is much less important than solution in causing inequilibrium Radon is one of the

daughter elements of uranium. It is a heavy gas with half life of 3.8 days. Being a gas, radon can move by gaseous diffusion. Within rocks it normally diffuses only very short distances because of its comparatively short half life; after 5 half lives (approximately 20 days) radon is almost completely disintegrated to RaA, a solid element, and further gaseous diffusion is stopped.

Radon also produces abnormal background effects in confined spaces such as mine workings and tunnels. This is explained in chapter IV.

Chapter IV

PRACTICAL PROBLEMS

This chapter considers some of the problems that arise during the use of a counter in prospecting, geologic work, and mining.

BACKGROUND EFFECT

Most things are slightly radioactive. All rocks carry, on the average, a few thousandths of one percent uranium. Radioactivity is also produced by cosmic rays which strike the earth from outer space. Even the materials of which a counter is made have trace amounts of radioactive elements. All this means that a counter is constantly being bombarded by gamma rays, and whenever it is operating, the counter records the normal radioactivity of its surroundings. This is called the *background radioactivity* or *background count.*

Radioactive ore adds radioactivity to the usual background and hence it is the increase in radioactivity above background that is significant in prospecting.

In looking for radioactive ore, then, the first step is to determine the background radioactivity. With a counter having a headset or electric light, individual impulses can be counted and totalled for a period of 1, 2, or 3 minutes (the longer periods provide more accurate readings). With a metered counter, the fluctuations of the needle can be visually averaged over a similar length of time. Some counters are equipped with an adjustment which automatically subtracts the background count from the meter indication.

Background radioactivity changes from time to time and from place to place; hence the background count should be checked periodically. Readings at one spot vary slightly from time to time due to such things as change in cosmic count, change in sensitivity of the counter, or weather changes. The change in counter sensitivity may be caused by weakening of the batteries, aging of the electronic components, or, sometimes, temperature changes.

The background may vary markedly from place to place, due usually to differences in the normal radioactivity of the surface rocks. Igneous rocks, such as granite, are more radioactive than most sedimentary rocks, such as limestone, sandstone, and shale. Among the sedimentary rocks, black shale and phosphate-rich rocks are the most radioactive; pure limestones are the

least radioactive; sandstones vary widely in radioactivity. The average radioactivity of some common rocks is noted below. The measurements were made above a level outcrop; the figures show relative radioactivity, not actual counter readings.

TABLE 2—AVERAGE RADIOACTIVITY OF COMMON ROCKS

(After Russell)

Shale	2 to 7; average 4 to 6
Sandstone	1 to 7; average 1.5 to 4
Limestone	1 to 3
Light igneous rock (such as granite)	5 to 12
Dark igneous rock (such as basalt)	3 to 6

It is apparent that background radioactivity is influenced by the type of rock in the area where the reading is measured. When passing from one rock type to another, say from limestone to granite, the background may increase markedly as a result of the change in bedrock.

ABSORPTION EFFECT

It has been noted earlier that gamma rays from uranium minerals are absorbed by approximately:

3 inches of lead
1 foot of rock
2½ feet of water
Several hundred feet of air

In one test Bateman reports that "80 pounds of high-grade pitchblende ore were placed in a mine working separated by 2½ feet of solid rock from an adjoining working. No significant radioactivity could be detected through the rock."

Many counter users are prone to overrate the penetrating power of gamma rays. It should always be remembered that almost all the gamma rays that hit the counter come from a surface shell of rock about 1-foot thick; the effect measured by the counter is little more than "skin deep" regardless of the type of counter.

COVER EFFECT

Soil or other overburden tends to absorb the gamma rays given off by bedrock. Where soil is more than one or two feet thick, a surface reading gives the radioactivity of the soil, not the underlying rock. Readings are usually higher when taken over a rock exposure than when taken over the same kind of rock covered by soil, as illustrated by the following pairs of measurements made with Geiger counters.

TABLE 3—EFFECT OF COVER

	Reading (counts/minute)
Over barren granite, LaBine Point, Northwest Territory, Canada *	89–90
Over granite concealed by overburden *	60–65
Over barren granite, Grand Junction, Colo	56
Over granite concealed by overburden	51

(*After Ridland)

Readings taken above soil are not so reliable as those taken above rock, but still, under favorable conditions, soil measurements have been used to obtain a clue to the radioactivity of the rocks below. For example, at the Nicholson deposit, Saskatchewan, a radiation survey indicated a hitherto unknown zone of radioactivity (Fig. 9). The radioactive zone was explored, and stripping uncovered a new vein of pitchblende under about six feet of overburden. The radioactivity, however, was not due to gamma rays which passed from the pitchblende through 6 feet of soil; rather, the high radioactivity count was due to an accumulation in the soil of radioactive elements derived from the weathering of pitchblende. The soil was sampled and checked periodically with a counter. It was found that the soil lost its radioactivity at a rate which suggested that radon was responsible for part of the radioactivity.

Radioactivity measurements made over certain soils are apt to be quite unreliable. For example, unreliable readings may be obtained in areas of glacial drift, where the soil is not produced by weathering of the underlying rocks. Readings may also be unreliable where uranium ore is being mined, hauled, or milled. Radioactivity surveys in the uranium producing area of western Colorado reveal high radioactivity on the downwind side of haulage roads.

COSMIC EFFECT

Cosmic rays are radiations which strike the earth from outer space. They are important here because they account for some of the radioactivity measured at the ground surface. The contribution of cosmic activity to the total radioactivity measured at any point is variable. Cosmic activity increases with elevation and varies from time to time due to cosmic disturbances.

One test at Oak Ridge, Tenn., indicated that 35 percent of the radioactivity measured at ground surface by a scintillation counter was due to cosmic activity.

A measure of the contribution of cosmic rays can be made by reading the counter in a boat at some distance from shore. Radioactivity from underlying rocks is absorbed by the water, and the counter then records primarily the gamma radiation from cosmic rays, plus

slight radiation due to the air, the boat, the observer, and the lake shore. A series of such measurements, made on lakes at various elevations, illustrates the strengthening of cosmic count upward. The figures represent relative radioactivity, not actual counter readings (table 4).

Because scintillation counters have a smaller sensitive element than Geiger counters and both types have about equal efficiency for detecting cosmic rays, the relative contribution of cosmic counts is less with a scintillation than with a Geiger instrument.

TABLE 4—EFFECT OF ELEVATION ON COSMIC RAY ACTIVITY

(After Russell)

Lake	*Elevation above sea level, feet*	*Relative radioactivity due to cosmic rays*
Country Club Lake, Bryan, Tex	300	1. 4
City Park, Denver, Colo	5, 250	2. 6
Barren Lake, Grand Mesa, Colo	10, 000	9

TOPOGRAPHIC EFFECT

Cosmic rays are responsible for an effect that is sometimes puzzling: in a gully or sharp valley the background radioactivity may be different from the background measured on a nearby level surface.

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Figure 4 (A-C) illustrates this effect. On level ground (A) the counter is exposed equally to radioactivity coming down from cosmic rays and coming up from the ground. In a gully (B) some of the cosmic rays are cut out and a larger proportion of the radioactivity comes from the ground. The counter reading may increase, decrease, or remain constant, depending on the relative intensity of radiation from the ground and from cosmic rays. In a mine or tunnel (C) cosmic rays are eliminated by absorption and all radioactivity comes from the surrounding rock. Readings made underground may be considerably higher or lower than those at the surface.

MASS EFFECT

A counter reading may be strongly influenced by the size of the sample tested, particularly if it has above-average radioactivity. A large piece of rock gives off more gamma rays than a small piece, and hence different counter readings can be obtained from specimens of different sizes having the same uranium content.

The mass effect can be demonstrated by comparing (fig. 5) the reading obtained from a hand specimen (A), with a reading taken against the rock face from which the hand specimen was taken (B), and with a reading

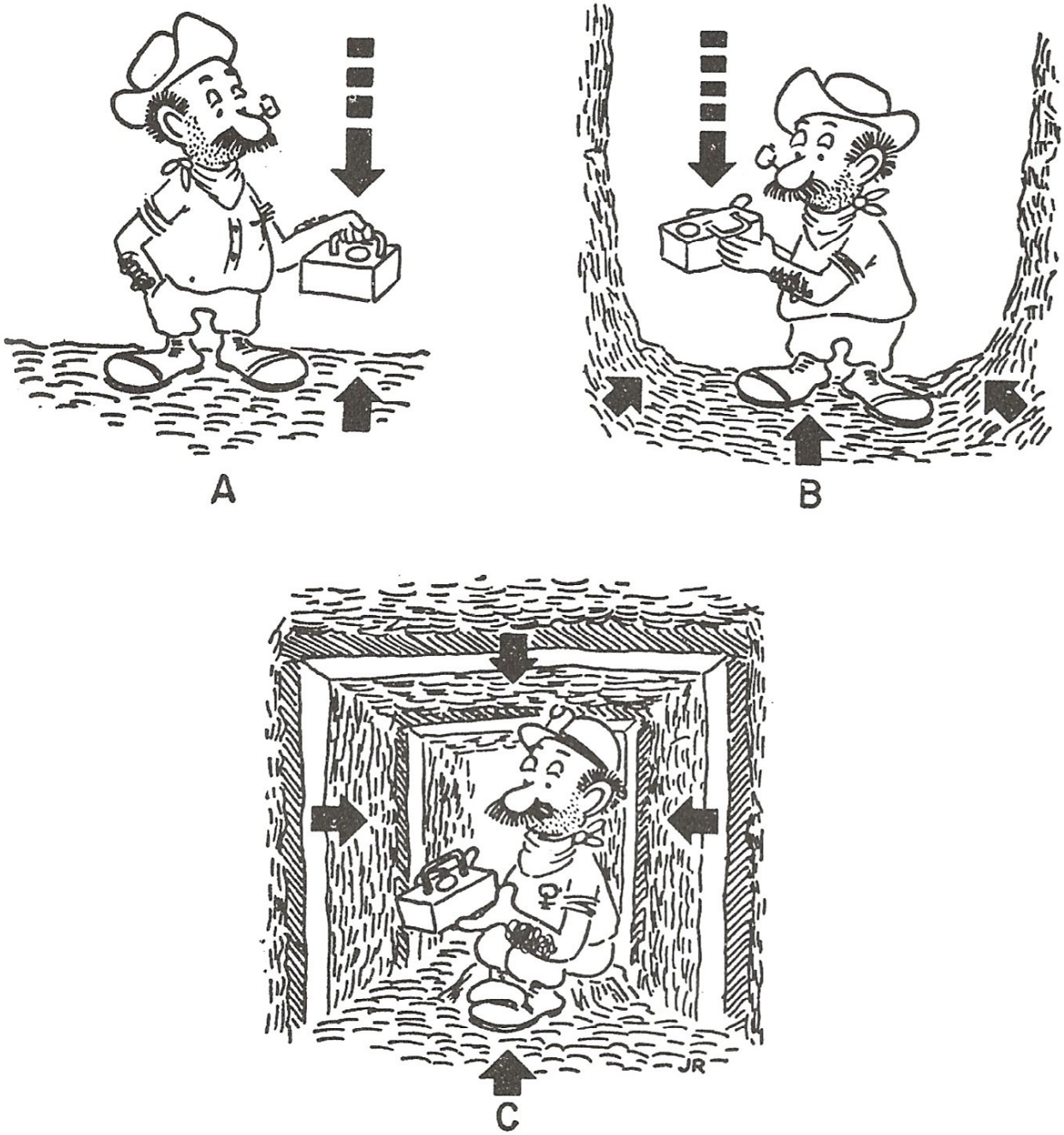


FIG. 4.—Topographic effect. On level ground (A) the counter can receive equally well cosmic radiation from above (dashed arrow) and ground radiation from below (solid arrow). In a gully (B) part of the cosmic count is cut out and in a mine working (C) cosmic count is eliminated.

taken with the counter inserted into a crevice within the rock (C). The measurements shown in table 5 were made with a Geiger counter on barren granite at Grand Junction, Colo.

Mass effect is most marked with uranium ores and with rocks of above-average radioactivity, such as the granite mentioned above. With rocks of average radioactivity, such as most barren sandstone, little mass effect can be noted. If cosmic activity is high, it is even possible to obtain a lower reading within a rock crevice than with a hand specimen because some cosmic rays are absorbed by the rock.

Mass effect is particularly important to the uranium miner because he commonly tests rocks of high radioactivity. Some miners have the impression that a counter which has been checked against a hand sample of known uranium content can be used to directly estimate the grade of an ore pile. Complete confidence in the Geiger counter has sometimes resulted in costly mistakes in uranium mining. Some material which was shipped to the mill as ore, on the basis of a counter reading (fig. 6) was rejected because the uranium content was below the acceptable minimum of 0.10% U_3O_8.

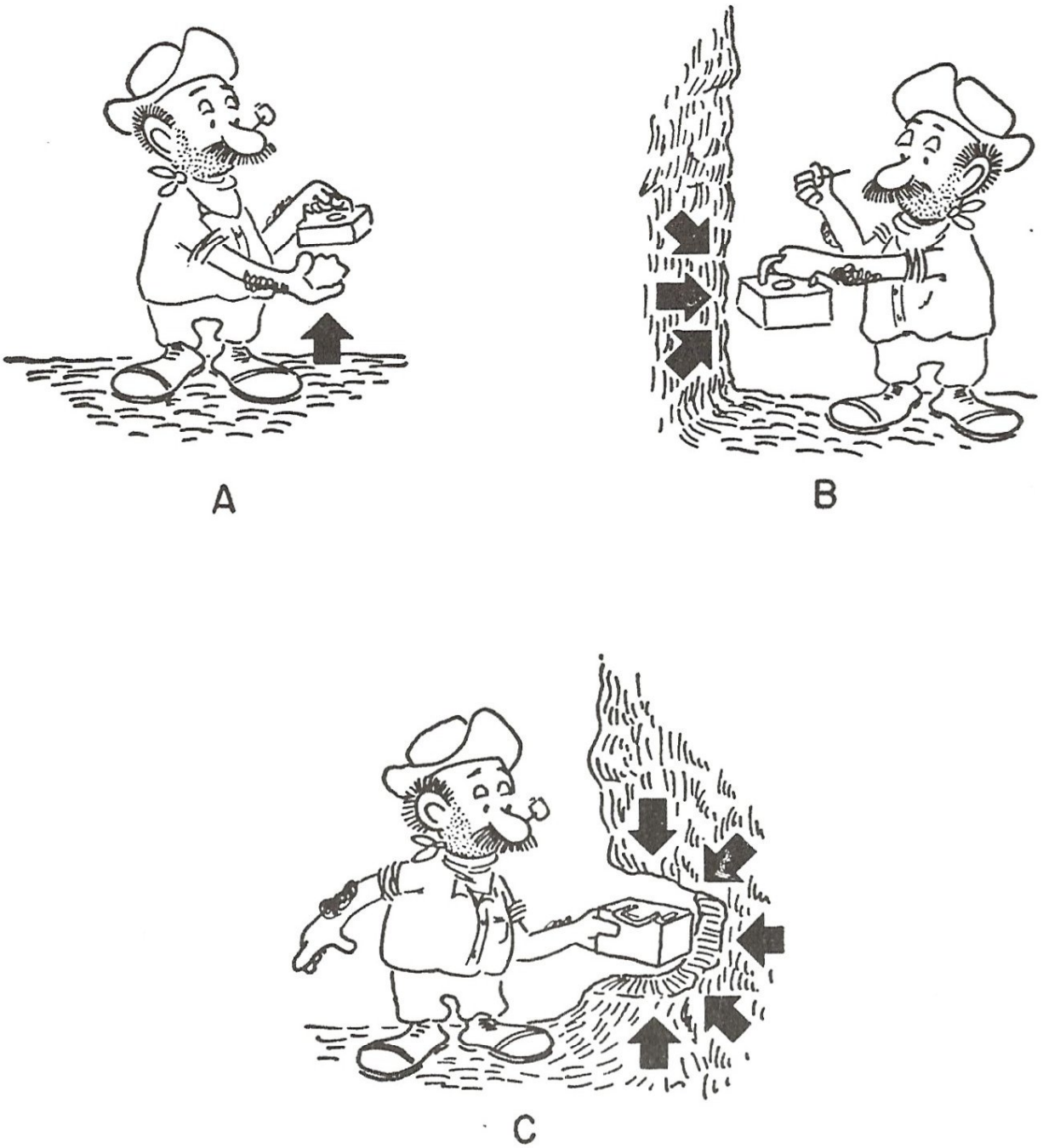


FIG. 5.—Mass effect. The counter receives more gamma rays from a rock face (B) than from a hand specimen (A), and even more when the counter is inserted into a rock crevice (C).

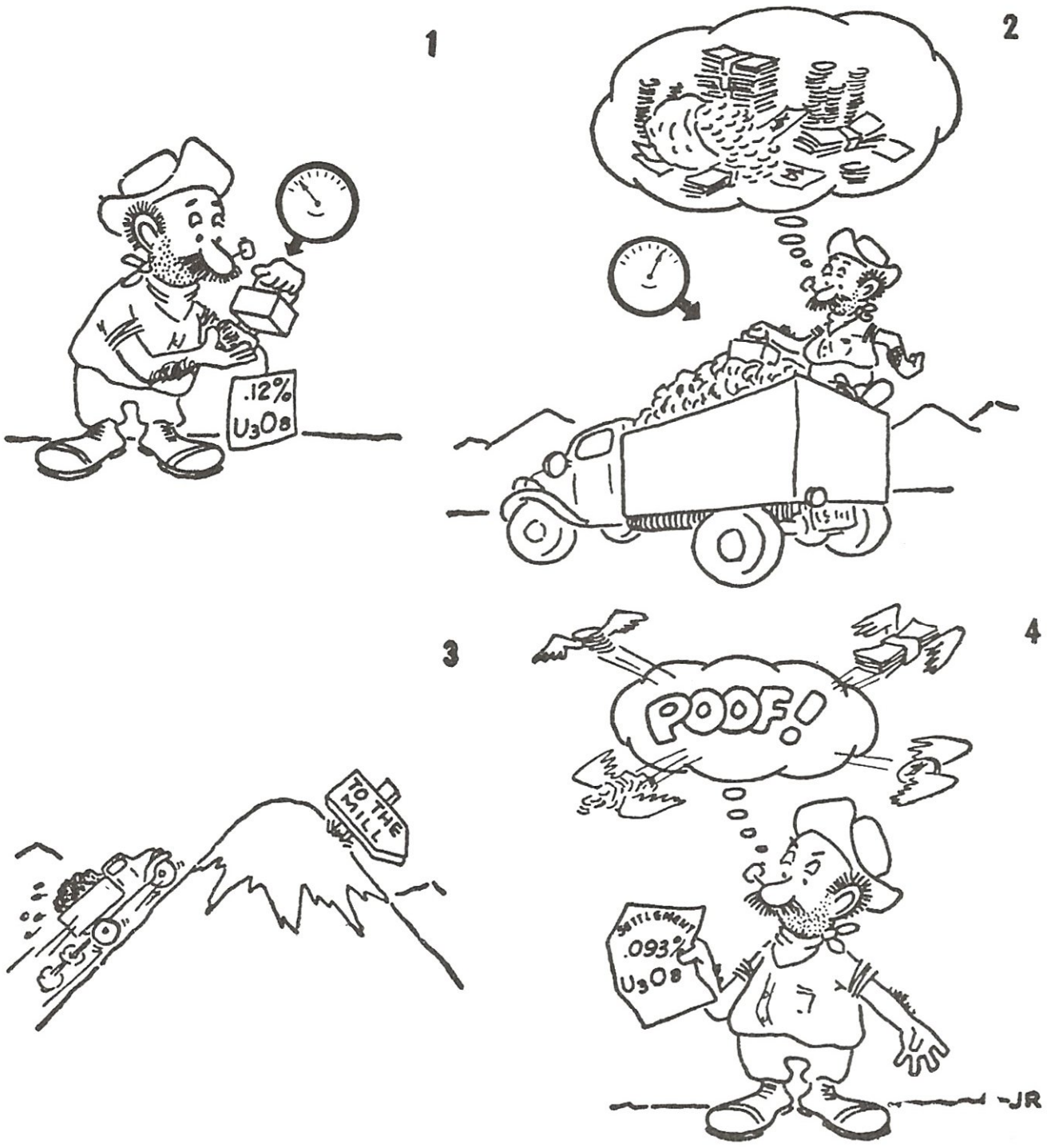


FIG. 6.—He forgot the mass effect!

TABLE 5—MASS EFFECT

	Reading (counts/minute)
Small hand specimen	48
Rock face	60
Crevice within the rock face	79

EQUILIBRIUM EFFECT

One of the most perplexing problems in using a counter is the matter of radioactive equilibrium. As discussed in chapter III, a counter cannot measure uranium directly; rather it responds to the gamma radiation of some of uranium's decay products. A counter can give a reliable measure of the uranium in a sample only when the decay products are present in their appropriate amounts; that is, when the sample is in equilibrium. A chemical analysis, on the other hand, measures uranium directly and is not influenced by the presence or absence of decay products. When a uranium assay made by a radioactivity measurement does not agree with one made by a chemical method, the chemical assay is considered to be correct, assuming that the analytical work is accurate. Lack of equilibrium is a common cause of inaccurate assays made by radiometric methods.

Since it is not possible in the field to correct counter readings for lack of equilibrium, the next best thing is to learn how to recognize ores which may not be in equilibrium. Fortunately, experience has shown that most uranium ore produced in the United States is in equilibrium:

1. Carnotite ore, such as that mined in western Colorado.
2. Fresh, unweathered pitchblende ore, such as the veins at Marysvale, Utah, and the deposits in the Shinarump formation of southeast Utah.
3. Asphaltic uranium ore from Temple Mountain, Utah.
4. Carnotite-tyuyamunite-uranophane ore from Grants, N. Mex.

All other radioactive materials should be viewed with suspicion—they may not be in equilibrium, and a chemical assay should be obtained to check the reliability of counter readings. Specifically, the following materials are apt to be out of equilibrium:

1. Deposits containing secondary uranium minerals such as autunite, schroeckingerite, or torbernite. The schroeckingerite deposits in Sweetwater County, Wyo., and the autunite deposits of the White Signal district, Grant County, N. Mex., are out of equi-

librium. But as noted above, deposits at Grants, N. Mex., which contain secondary minerals, are an apparent exception to this rule—they are in equilibrium.

2. Weathered radioactive deposits which contain oxidized sulphide minerals such as pyrite and chalcopyrite. The weathered portions of uranium deposits in the Shinarump formation and the weathered portions of pitchblende veins at Marysvale, Utah, are out of equilibrium.
3. Weathered radioactive fissures and veins of all types.
4. Radioactive coatings on mine workings.
5. Radioactive spring deposits.

Even though most radioactive materials which are out of equilibrium contain too little uranium to be economically mined they sometimes provide clues to the presence of uranium ore. A radioactive vein outcrop, even though it contains little uranium, may indicate the presence of pitchblende at depth. Discovery of a radioactive spring deposit in Arizona led to the discovery of a pitchblende deposit nearby (fig. 10).

RADON EFFECT

Erratic counter readings can result from concentrations of radon, the gaseous decay product of uranium.

Like uranium, radon is not a gamma emitter and hence it cannot be directly detected with a Geiger counter. However, its short half life and the very short half lives of its immediate daughters—RaA (31 minutes) and RaB (27 minutes)—permit rapid formation of RaC, the most powerful gamma emitter of the whole uranium series. These radioactive daughter elements may adhere to dust particles and remain suspended in the air, and they may collect on exposed surfaces of any kind. In a mine with radon contamination these elements may collect on clothing so that it remains radioactive for several hours. In the same way deposition of these radioactive products on a Geiger counter causes its readings to fluctuate widely and remain abnormally high for several hours. Where air is contaminated by radon and its daughters, a counter is almost useless.

Radon contamination may be a problem in confined spaces, such as mine workings and tunnels, particularly where ventilation is poor. Its effects are also noticeable where rock is being broken, as by drilling or blasting. When the rock is shattered many new rock surfaces are formed from which radon can escape.

Radon usually is most troublesome in mines and underground work.

THORIUM EFFECT

In addition to uranium, several other elements are also radioactive, but only one of these—thorium—is sufficiently abundant to create special problems in operating a counter.

Thorium, like uranium, is the parent of a radioactive series which has 11 radioactive members and ends with lead. The gamma activity of the thorium series is about two-fifths that of the uranium series; in other words, rock containing 0.1 percent uranium activates the counter as much as rock with 0.25 percent thorium. Fortunately uranium ore produced at present in the United States does not contain appreciable thorium, and the radioactivity is due mostly to the uranium series. Hence the contribution of thorium to the radioactivity of most uranium ores is negligible.

Uranium and thorium do, however, occur together in igneous rocks, such as granite, and in pegmatite veins which occur in and near granite bodies. Therefore when prospecting granitic terrain it should be remembered that some of the measured radioactivity is probably due to thorium.

UNDERGROUND EFFECT

Mine workings present special problems in operating a counter; for example—

1. The instrument is surrounded by rock on all sides and, as a result, the mass effect is intense.
2. Most cosmic rays are absorbed by passage through rock and hence their effect is reduced or eliminated in mine workings.
3. Radon contamination may be a problem.
4. In some mines, particularly those which are moist, the rock surfaces are coated with irregular patches of radioactive compounds. These are produced after mining by the action of ground water, which dissolves radioactive salts elsewhere and deposits them by evaporation on exposed rock surfaces and mine faces. Usually these materials are fluorescent under ultraviolet light. Such radioactive coatings constitute only a thin film and do not represent a minable volume of material, but they may be indicative of nearby radioactive minerals.
5. Only counters which are moisture-sealed by the manufacturer can be expected to operate effectively in a moist mine.

Background readings in a mine are usually higher than those over similar rocks at the surface, but some-

times the reverse is true. For example, the background in zinc mines in limestone at Balmat, N. Y., is less than the background at the surface. Here the decrease in radioactivity due to absorption of cosmic rays underground is larger than the increase in radioactivity due to the mass effect of the limestone, which has low radioactivity.

Chapter V

SPECIAL USES

RADIOMETRIC ASSAYING

The most reliable way to determine the uranium content of a sample is to obtain a chemical analysis. A chemical analysis determines uranium directly, and it is not affected by decay products and thorium, which influence a Geiger counter. Analyses are expressed in terms of uranium oxide, U_3O_8. To indicate that an assay was made by chemical methods the symbols "U_3O_8 chem." or "U_3O_8c" are usually used.

If a sample is in radioactive equilibrium, a fairly accurate uranium analysis can be made by measuring its radioactivity. Such measurements are best made with laboratory counters especially designed for the purpose. The sample is crushed, ground, and placed in a sample holder surrounded by a lead shield which reduces the background count. The instrument accurately records the number of counts received during a several-minute period. The radiometric assay can then be determined

from the recorded count by the use of a chart such as that shown in figure 7, which is individually prepared for each counter.

The resulting analysis is expressed as "uranium equivalent." This means that the radioactivity of the sample is equivalent to the radioactivity of a sample which contains the amount of uranium indicated by the analysis. For example, 0.26 percent uranium equivalent means that the sample gives off as much radioactivity as a sample which is in equilibrium and contains 0.26 percent U_3O_8, with no thorium present. To indicate that an assay was made by radiometric methods the symbols "U_3O_8 equiv.," "U_3O_8e," or "U_3O_8 rad." are usually used.

Although field counters are not designed for assaying, an experienced operator can become fairly accurate in estimating equivalent uranium content from counter readings. A hand specimen can be used, but if more reliable results are desired, the procedure can be improved in the following ways—

1. Crush the sample and place some of it in an open holder, such as a small cardboard box or glass bottle; always use the same type sample holder. In this way the mass effect of specimens having different sizes is eliminated.

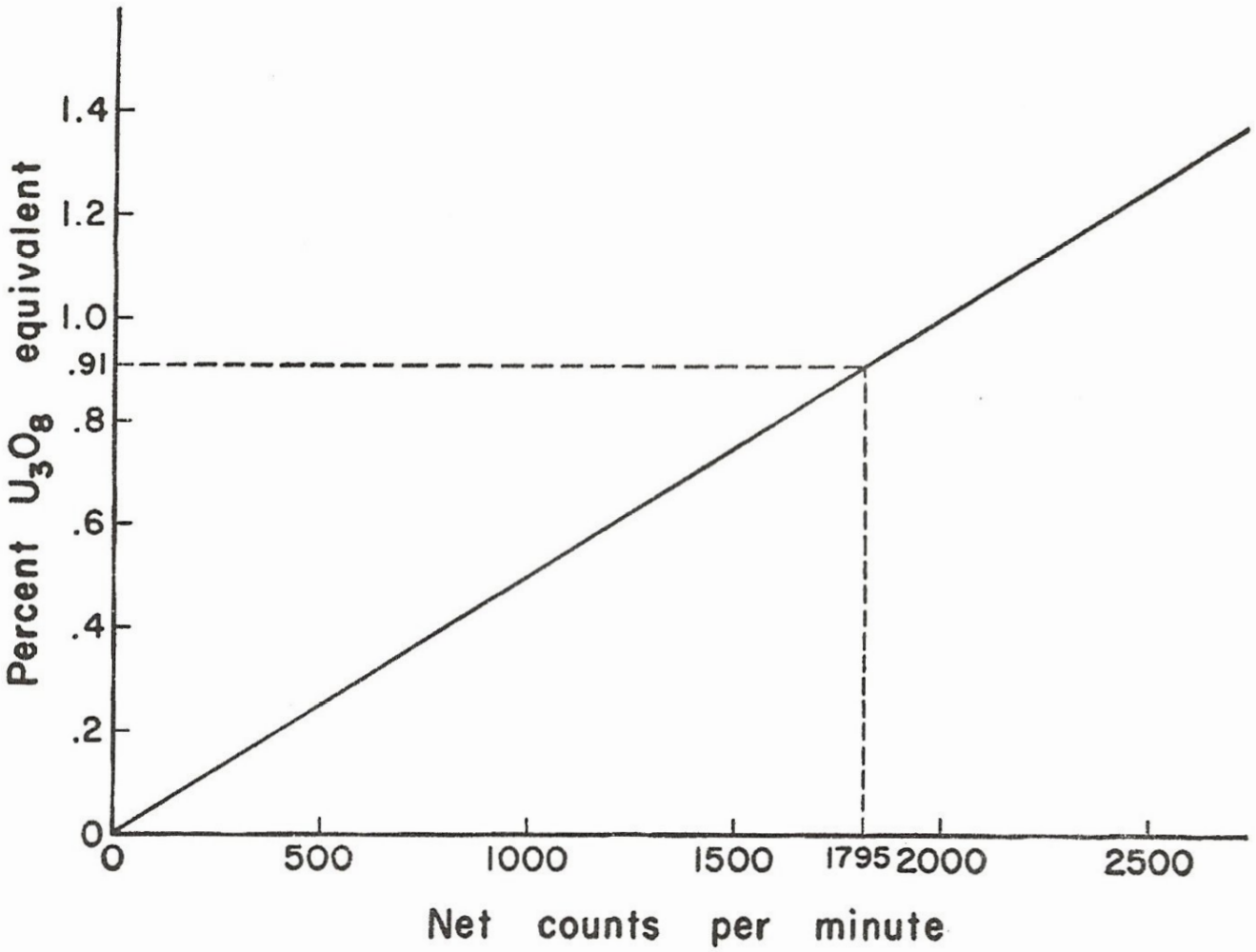


FIG. 7.—Calibration chart for a laboratory counter. By use of the graph the radioactivity of a rock sample can be recalculated as percent U_3O_8 equivalent; for example, a sample which yields 1795 net counts per minute assays 0.91 percent U_3O_8 equivalent. A calibration chart can be used only for the counter for which it was prepared.

2. Standardize the relative position of the counter and the sample. This reduces the mass effect due to variable distance.

3. Provide a lead shield around the counter and the sample. This reduces the background radioactivity.
4. Check the operation of the counter by periodically testing the same check sample. Any change in the sensitivity of the instrument due to weakening batteries or other causes can be noted in this way.

After the assaying procedure is standardized, the radioactivity of several samples with different uranium content is measured. The samples are also analyzed chemically for uranium and the chemical assay is plotted against radioactivity (fig. 8). Note that the net count (total count less background count) is used. The graph can now be used to convert counter readings to equivalent uranium assays.

It should always be remembered that any counter assay—whether made by laboratory or field methods—is reliable only if the sample is in equilibrium. Failure by miners to recognize this limitation of a counter has resulted in costly mistakes. For example, a load of rock was mined from the outcrop of a uranium deposit in the Shinarump formation in Circle Cliffs, Garfield County, Utah. Field assays by Geiger counter indicated that the material was of ore grade, and so it was trucked several hundred miles to a uranium mill. By chemical assay the shipment was found to contain less

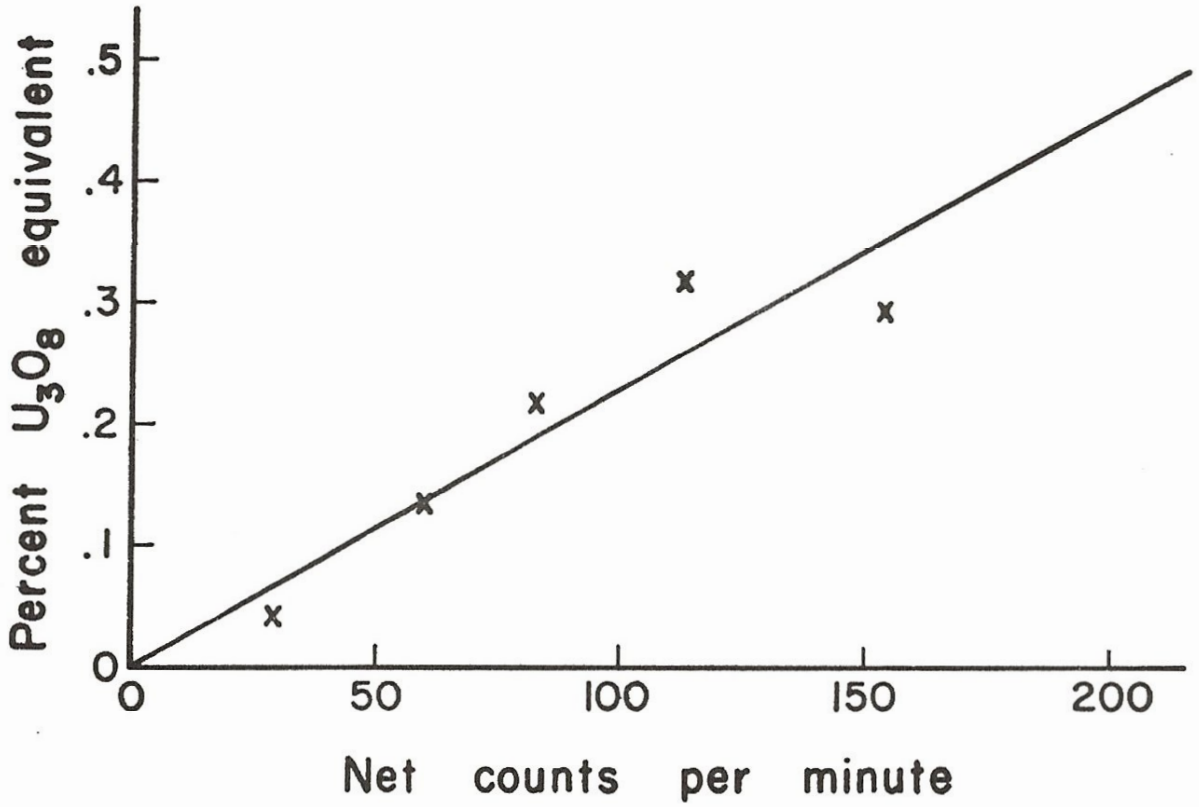


FIG. 8.—Calibration chart for field counter. This graph was prepared by plotting the radioactivity of five assayed samples, indicated by x. A field counter is less sensitive than a laboratory counter and hence detects fewer counts for a given amount of uranium, counted for the same time interval.

than 0.1 percent U_3O_8, the minimum required by the mill, and the shipment was rejected without payment.

RADIOMETRIC SURVEYS

After an area of radioactive rocks is discovered, it is often helpful to make a systematic survey of the radioactivity. When the results of such a survey are

plotted, the pattern of radioactivity may furnish significant information about the size and trend of the radioactive areas. This information is readily obtained from surface measurements and can be very useful in planning sampling, test pitting, diamond drilling, or other exploration.

Counter readings are made at a series of survey points. To obtain uniform coverage of the area the survey points can be established on a grid pattern with stations spaced 50 or more feet apart, depending on the size of the area and the variations in radioactivity. Readings should be taken over a counting period of at least one minute, in order to obtain accurate measurements. With a recording meter the needle fluctuations can be averaged by eye; with other instruments the actual number of individual counts is recorded.

After counter measurements are made at all survey points, these points and the corresponding readings are plotted on a map. The readings can be expressed in one of several ways:

1. Actual counter reading, whether this is recorded in counts per minute or mr/hour, is recorded on the map. The survey of the Annie Laurie claim (Fig. 10) was plotted in this way .
2. Net counter reading, in counts per minute or mr/hour. These figures are obtained by subtracting

background readings from readings obtained during the survey.

3. Ratio of counter reading to background. For example, a reading of 93 counts per minute in an area where the background is 60 gives a ratio of $^{93}/_{60} = 1.56$

The second and third methods are generally preferable because they eliminate the background count. Background is determined by taking the average of several readings immediately outside the area being surveyed.

After the counter readings are plotted, lines can be drawn between points of equal radioactivity to aid in visualizing the variation in radioactivity within the area surveyed. Figures 9 and 10 illustrate the use to which such maps can be put. On the Jim claim, figure 9, a small sharp radioactivity high was found in the northern portion and here a hitherto unknown vein of pitchblende was discovered by stripping. The radioactivity survey of the Annie Laurie prospect, figure 10, was helpful in planning test pitting and sampling of the deposit.

SPECIAL APPLICATIONS

For certain specific jobs, special counters have been devised. For example, counters carried in low-flying

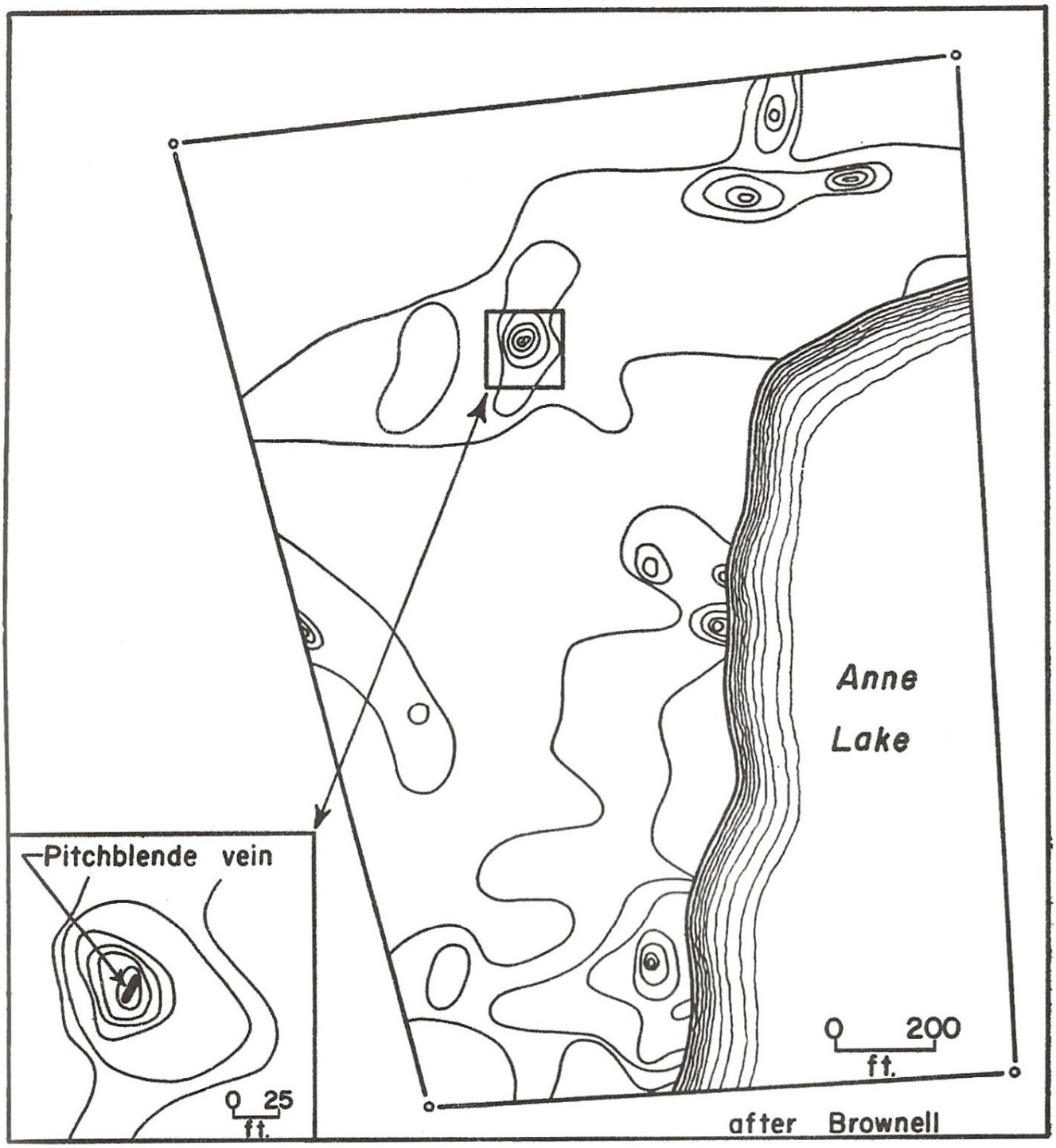
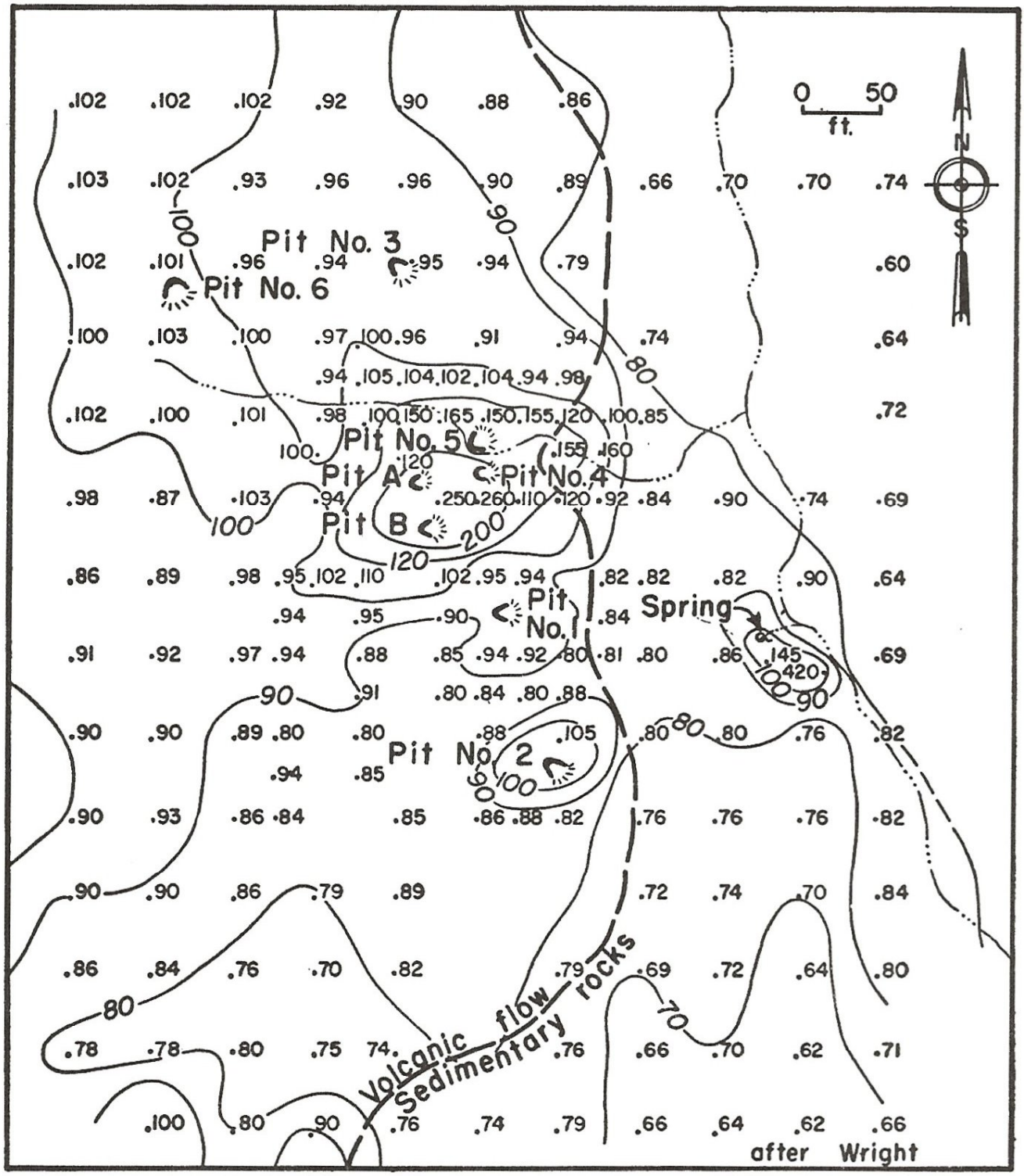


FIG. 9.—Radiation survey of the Jim claim, Saskatchewan. The survey of this claim showed a previously unknown radioactivity high in the northern portion of the area. Exploration here resulted in the discovery of a pitchblende vein.


0 50
ft.
N
S
Pit No. 3
Pit No. 6
Pit No. 5
Pit A
Pit No. 4
Pit B
Pit No. 1
Spring
Pit No. 2
Volcanic flow rocks
Sedimentary rocks
after Wright

planes have been successful in discovering new uranium deposits in parts of the Colorado Plateau. The usual Geiger counter does not have adequate sensitivity for this airborne work and hence a scintillation counter is commonly used. Other custom-built devices have also been tested in the air. These achieve high sensitivity by using sets of large Geiger tubes, or high efficiency Geiger tubes, or crystal counters.

Another special use to which counters are being put is the testing of holes which have been drilled to explore a uranium deposit. Counters are available which have a long cable connection which permits the probe to be lowered into a drill hole. With the average Geiger counter uranium mineralization cut by the drill hole can be detected. With a probe of high sensitivity, uranium mineralization can be detected and the types of rock cut by the drill hole can be identified.

FIG. 10.—Radiation survey of the Annie Laurie prospect, Arizona. This survey was used to locate the test pits. Note the difference in background radioactivity between the sedimentary rocks and the volcanic flow. Radioactivity was first discovered here when the spring deposits were tested with a counter.

Chapter VI

COUNTER MAINTENANCE

With the exception of the Geiger tube itself, all the components of a Geiger counter are standard electronic items, and hence many repairs can be done by a qualified radio serviceman. Usual test equipment, however, cannot check the Geiger tube, and when this is thought to be functioning improperly the operation of the counter can best be checked by substitution of a new Geiger tube. A radioman can also change the time-constant of the instrument, if that is desired.

Many operating difficulties are due to weakening of the power supply, which can be remedied by battery replacement. Geiger counters require three types of power supply—1, high voltage (900–1,000 volts) for the Geiger tube, 2, medium voltage (about 90 volts) for the plates of the amplifying tubes, 3, low voltage (1.5 volts or 6 volts) for the tube filaments. In many models the power is supplied by three sets of batteries. Some counters, particularly the lightweight models, operate

on 1 or 2 sets of batteries. At least one counter uses only flashlight batteries.

Batteries can be readily replaced provided the *manufacturer's instructions are carefully followed*—otherwise there is danger of shock from the high voltage. Fortunately the high voltage batteries, which are most expensive, have a fairly long life under normal use. The 90-volt plate batteries normally fail first.

Except for battery replacement, counter repairs should be done by a qualified electronics serviceman or by the manufacturer.

High humidity may short the power supply, unless the counter is of a type which is sealed by the manufacturer against moisture.

If the counter is contaminated by radon, radioactive particles or dust, it will not operate correctly until the radioactive materials have completely decayed. The counter should not be put into contact with ore samples, contaminated clothing, radioactive dust, or contaminated mine air.

Chapter VII

QUESTIONS AND ANSWERS

1. QUESTION. Is a license required to prospect with a counter?

ANSWER. No, a license from the Atomic Energy Commission is needed, however, before uranium ore that has been mined can be sold.

2. QUESTION. How can I learn more about prospecting for uranium?

ANSWER. By reading Prospecting for Uranium, for sale by the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C. Price—55 cents.

3. QUESTION. I have been told that drill holes in uranium-bearing rock are more radioactive when first drilled than later. Is this true?

ANSWER. This may be true because of the release of radon during drilling. As radon and its daughters decay, the radioactivity declines.

4. QUESTION. Is it true that a scintillation counter has greater penetration than a Geiger counter?

ANSWER. No. Both counters can receive only the gamma rays which come from the outer foot of a rock outcrop.

5. QUESTION. What is meant by "uranium equivalent"?

ANSWER. "Uranium equivalent" means that quantity of uranium (in equilibrium) which will produce the observed amount of radioactivity.

6. QUESTION. Can I get a counter which will assay for uranium?

ANSWER. No counter can give an accurate assay unless the sample is in radioactive equilibrium. Some counters are made with adjustments which maintain constant sensitivity, and some are calibrated directly in U_3O_8. Both of these improvements facilitate radiometric assaying.

7. QUESTION. What is the effect on the counter of snow on the ground?

ANSWER. Snow absorbs gamma rays. Its effect is equal to the absorbing effect of the water it contains. One foot of snow contains 1 to 2 inches of water.

8. QUESTION. Are there any elements other than uranium and thorium which affect a counter?

ANSWER. Yes, several other elements are slightly radioactive. The only one which may possibly be important in field work is potassium, but its radioactivity is only $\frac{1}{2500}$ that of uranium in equilibrium.

9. QUESTION. In prospecting for uranium how high should a counter reading be to be of interest?

ANSWER. Any reading of two or three times background, or more, should be investigated.

10. QUESTION. I know of a tunnel where the counter gives four times the reading at the surface. Does this mean that uranium ore is there?

ANSWER. Most likely the high reading is due to the mass effect of the rock in the tunnel, and possibly to the effect of radon as well.

11. QUESTION. A specimen I took from an outcrop gave a high count when I collected it, but at home it doesn't give much of a kick. Is this due to radon?

ANSWER. Probably not. The high radioactivity which you measured first was probably due in part to the mass effect of the rocks from which the specimen was taken. At home you are free from this mass effect.

12. QUESTION. How can I tell whether my counter is operating correctly?

ANSWER. One way is periodically to take a reading on a check piece of radioactive rock. The luminous

dial of a watch can also be used for this purpose. The readings should always be about the same; if not, the counter may need attention.

13. QUESTION. I know a place where I can get a higher count from a hand specimen than from a rock crevice. What is the reason for this?

ANSWER. The radioactivity from the rocks is lower than the radioactivity from cosmic rays. In a crevice some of the cosmic rays are absorbed by the overlying rock.

14. QUESTION. My counter doesn't work well when the temperature drops to about freezing. Why is this?

ANSWER. Some Geiger tubes contain gases which condense at low temperatures. The only way to avoid your problem is to keep the tube warm.

15. QUESTION. What is the effect of an atomic explosion on a prospecting counter?

ANSWER. Atomic test detonations at the AEC's Nevada Proving Ground near Las Vegas, Nevada, often result in high background radioactivity in areas east of the proving ground. Blasts have interfered with prospecting as far away as South Dakota. The increase

in radioactivity is especially marked if rain or snow falls shortly after the blast and drives airborne radioactive particles to the ground level. Usually the effect lasts only a few days.

APPENDIX A

Manufacturers and Distributors of Portable Radiation Detection Instruments Suitable for Prospecting

This is a list of firms that have come to the attention of the Commission as currently manufacturing and/or distributing radiation detection instruments for prospecting. Since the Commission does not recommend specific manufacturers, dealers, or models of instruments, inclusion of a name on this list does not signify endorsement by the Commission, nor does omission of any company signify the Commission's disapproval of that company or its products.

Anton Electronic Laboratories, Inc.
1226–1238 Flushing Avenue
Brooklyn 37, N. Y.

Atomic Instrument Co.
84 Massachusetts Avenue
Cambridge 39, Mass.
(Distributor, drill hole counter, portable scintillation counter.)

Atomic Research Corp.
1405 Mesita Road
P. O. Box 205
Colorado Springs, Colo.

V. G. Baker
Fairbanks, Alaska

Berkeley Division of Beckman Instruments, Inc.
2200 Wright Avenue
Richmond, Calif.

Canadian Aviation Electronics, Ltd.
(Formerly Halross Instrument Corp.)
387 Sutherland Avenue
Winnipeg, Manitoba, Canada
(Scintillation counter.)

The Detectron Corp.
5420 Vineland Avenue
North Hollywood, Calif.

E. A. K. Research Laboratory
P. O. Box 62
Tarrytown, N. Y.

Electronic Associates, Ltd.
4616 Yonge Street
Willowdale, Ontario, Canada
(Drill hole counter, scintillation counter.)

El-Tronics, Inc.
Fifth and Noble Streets
Philadelphia 23, Pa.

Engineers Syndicate, Ltd.
5011 Hollywood Boulevard
Hollywood, Calif.
(Portable, airborne and drill hole scintillation counters.)

Fisher Research Laboratory, Inc.
1961–65 University Avenue
Palo Alto, Calif.

General Electric Co.
40 Federal Street
West Lynn, Mass.
(Scintillation counter *only*.)

Geophysical Measurements Corp.
801–805 Wright Building
Tulsa 3, Okla.
(Scintillation and drill hole counters.)

A. V. Herr Laboratory
5176 Hollywood Boulevard
Hollywood 27, Calif.

Herbach & Rademan, Inc.
1204 Arch Street
Philadelphia 7, Pa.

LaRoe Instruments, Inc.
P. O. Box 5906
Bethesda, Md.
(Scintillation counter.)

Menlo Research Laboratory
P. O. Box 522
Menlo Park, Calif.

Morgan Instruments Co.
21420 Valerie Street
Canoga Park, Calif.

National Electronic Police Devices, Inc.
Geological Instrument Division
P. O. Box 64575
Los Angeles, Calif.

Nielsen Blue Print, Inc.
108 North Third Street
Grand Junction, Colo.

Nuclear Enterprises, Ltd.
1124 Grosvenor Avenue
Winnipeg, Manitoba, Canada
(Airborne scintillation counter.)

Nuclear Instrument & Chemical Corp.
223 West Erie Street
Chicago 10, Ill.

Nuclear Measurements Corp.
2460 North Arlington Avenue
Indianapolis 18, Ind.
(Scintillation counter.)

Nuclear Research Corp.
2563 Grays Ferry Avenue
Philadelphia 46, Pa.
(Scintillation counter.)

Nucleonic Co. of America
196 De Graw Street
Brooklyn 31, N. Y.

Omaha Scientific Supply Corp.
3623 Lake Street
(Mail address: Box 1706)
Omaha 4, Nebr.

Plummer's Minerals
4720 Point Loma Avenue
San Diego 7, Calif.

Precision Radiation Instruments
2235 South La Brea Avenue
Los Angeles 16, Calif.
(Scintillation counter, drill hole counter.)

Professional Equipment Co.
149 Broadway
New York, N. Y.

R–C Scientific Instrument Co., Inc.
307 Culver Boulevard
Playa Del Rey, Calif.
(Scintillation counter.)

The Atomic Center
489 Fifth Avenue
New York 17, N. Y.

The Radiac Co.
489 Fifth Avenue
New York 17, N. Y.

Radiation Counter Laboratories, Inc.
Nucleonic Park
5122 West Grove Street
Skokie (Chicago), Ill.

Radio Specialists Co.
2620 Larimer Street
Denver 5, Colo.

Special Instruments Laboratory, Inc.
1003 Highland Avenue
Knoxville, Tenn.

Technical Associates
140 West Providencia Avenue
Burbank, Calif.

Tracerlab, Inc.
130 High Street
Boston 10, Mass.

Victoreen Instrument Co.
Medical Instrument Division
5806 Hough Avenue
Cleveland, Ohio
(Scintillation counter.)

Western Electronics
2818 North Nevada
Colorado Springs, Colo.

Western Radiation Laboratory
1107 West 24th Street
Los Angeles 7, Calif.

Whites Electronics
1218 M Street
Sweet Home, Ore.

APPENDIX B

Measurement Technique

The methods of radiation measurement affect interpretation of readings made in the field. Some of these procedures are considered briefly below.

Time-Constant

All counters having recording meters use an integrator circuit to operate the meter (fig. 1). The purpose of this circuit is to receive the irregularly spaced, individual impulses from the amplifying circuit and smooth them out to provide an average reading. An integrating circuit is quite simple, consisting essentially of a resistor and a condenser, and its effect depends on the size of these two electrical elements. With a large resistor and a large condenser, the circuit averages counts over a long period of time and the instrument is said to have a long time-constant. With a long time-constant, fluctuations of the meter needle are slight and the meter reading is stable, but the meter has a sluggish response to changes in radiation. With a short time-constant, the needle fluctuates widely, and an average reading may be hard to obtain.

Most counters are designed by the manufacturer to

reach a compromise between these two extremes. Some counters have several time-constants which can be selected by use of a switch.

If the time-constant of a particular instrument proves unsatisfactory, it can be modified by a radio serviceman.

Efficiency

All counters detect only a fraction of the gamma rays passing through them. The efficiency of a counter is a measure of this ability to respond to the radiation which strikes it. Efficiency depends upon the type of detector. Most commercially available Geiger tubes have less than 1 percent efficiency; in other words, the tube discharges only once during the passage of about 100 gamma rays through the tube. Improved Geiger counters have been developed with efficiencies of several percent, but they are not in wide use. The efficiency of a scintillation counter is considerably higher than that of a Geiger counter, ranging from 25 to 50 percent or higher. The efficiency of various scintillation instruments varies widely, dependent on the crystal size and type, and the counter design.

Statistical Error

All counter readings fluctuate due to the fact that gamma rays trigger the counter in random fashion, at

irregular intervals of time. This is readily noted with a counter having headphones or a neon light which detects individual impulses. It can be observed that they occur in irregular bunches or clusters, rather than in regular sequence.

The erratic reception of gamma rays introduces an unavoidable error into all counter measurements. The amount of such error is governed by laws of statistics, which state that the relative amount of error depends on the number of counts measured. It is possible to calculate the probable amount of error in a particular measurement by the following formula:

$$E=\frac{0.67}{\sqrt{N}}$$

E = probable relative error; N = total number of counts measured. For example, the probable relative error for a measurement of 16 counts is:

$$E=\frac{0.67}{\sqrt{16}}=\frac{0.67}{4}=0.168=16.8\%$$

The probable relative error for a measurement of 100 counts is:

$$E=\frac{0.67}{\sqrt{100}}=\frac{0.67}{10}=0.067=6.7\%$$

Accuracy is improved by increasing the total number of counts measured. This can be done in one of two ways—

1. increasing the length of the counting period, or
2. using an instrument which has high sensitivity, and hence receives a large number of impulses during the counting period.

The first method is immediately applicable to any field problem. It means, simply, that a reading averaged over a period of several minutes is more accurate than one averaged over a period of seconds. The longer counting period increases the number of counts measured, decreases the statistical error, and improves the accuracy of each measurement. The need for accuracy is, of course, determined by the purpose of the reading. To check quickly the radioactivity of an outcrop, a measurement of a few seconds duration with the ordinary counter is adequate. For determining background radioactivity the reading should be taken over a period of a minute. For more precise measurements, such as those required by a grid survey or a radiometric analysis for uranium, the counting period should not be less than several minutes.

The effect of the counting period on the accuracy of a given measurement is illustrated by the actual meas-

urements (see below), which were made with a laboratory counter on a sample of uranium ore.

With a counter having a recording meter, the length of counting period is determined by the time-constant of the integrating circuit; however, a long counting period can be obtained by making a visual average of needle readings over a counting period of sufficient length. As mentioned previously, a radio serviceman can change the time-constant of the counter by modifying the components of the integrating circuit.

EFFECT OF COUNTING PERIOD

Reading No.	Length of counting period			
	½ minute	1 minute	5 minutes	10 minutes
	Number of counts per minute			
1	50	55	51. 4	52. 7
2	32	44	48. 0	50. 8
3	60	56	51. 8	51. 5
4	44	45	48. 8	52. 8
5	52	50	50. 3	49. 9
Average	47. 6	50. 0	50. 1	51. 5
Average error of each reading—counts	7. 7	4. 4	1. 3	1. 0
Relative error of each reading—percent	16. 2	8. 8	2. 6	1. 9

Counting Rate

The number of counts detected within a particular counting period is dependent on two main factors:

1. The efficiency of counter. A scintillation detector yields more counts than a Geiger tube of the same size because of the difference in efficiency.
2. The size of the detecting unit. A large Geiger tube yields more counts than a small Geiger tube because more gamma rays pass through it; for the same reason a large crystal yields more counts than a small one.

An instrument with high counting rate is desirable because of the greater accuracy of its measurements. Except for the choice between a scintillation counter and a Geiger counter, however, there is little variation in counting rate among commercial field counters. Most models use Geiger tubes of approximately the same size (3 to 4 inches long) and efficiency. Some custom-made counters employ large Geiger tubes, but this improvement is unnecessary for average field work.

Sensitivity

The sensitivity of a counter is determined by its ability to detect small changes in radiation in a given

time. This is determined by the amount of statistical error. If the statistical error is great, small changes in counter reading are not significant and small variations in radioactivity cannot be detected. A counter with high counting rate has small statistical error and hence small variations in radioactivity can be detected—in other words, the counter has high sensitivity.

There is little variation in the sensitivity of most commercial field counters, except for the scintillation counter which is considerably more sensitive than the usual Geiger counter. The sensitivity of one counter can vary from time to time with the strength of its batteries, and the functioning of some counters is influenced by temperature changes.

SELECTED REFERENCES

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